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fragment of the Florida species in Dr. Torrey's herbarium, collected by the late Dr. Leitner. To the same species may safely be referred Bentham's *Piptolepis phillyreoides*, and probably Torrey's *F. angustifolia*, although this is more doubtful, as completely intermediate forms have not been met with. *Piptolepis*, as Dr. Torrey remarks, is identical with *Forestiera*, most, if not all, of the species producing some hermaphrodite blossoms.

Four hundred and seventy-sixth meeting.

February 14, 1860. — MONTHLY MEETING.

The PRESIDENT in the chair.

The Corresponding Secretary read letters from Messrs. Chauncey Wright and Simon Newcomb, of Cambridge, in acknowledgment of the notification of their election as Fellows. Also various letters relative to the exchanges of the Academy.

The Hon. Josiah Quincy addressed the Academy upon the subject of a memorial before the State Legislature, in behalf of the Boston Society of Natural History, and other societies, associated in the petition for a grant of land for practical scientific purposes. The subject of the memorial was also advocated by Professor Rogers and Mr. Emerson; and Messrs. Parsons, Loring, and Charles Jackson were appointed a committee to further the memorial before the Legislature.

Mr. Treadwell read a communication

On the Strength of Cast-Iron Pillars.

The great calamity which recently fell upon Lawrence having called the attention of the public to the subject of cast-iron columns or pillars, which are now so generally used in all our structures, I have thought that a few words upon this subject may not be without interest to the Academy. It may happen, moreover, that after considering the state of knowledge upon the subject, and the glaring discrepancies and contradictions contained in the practical rules and tables in common use by builders, the Academy may see fit to adopt some action tending to a revision of these guiding rules.

We have no record of any experiments to determine the power of iron to resist a force applied, in any of the four or five ways in which it may be applied, to break it, until about a hundred years ago, although such experiments might have been made and kept as secrets, or passed as traditions in the trade. About a hundred years ago, Musschenbroek made numerous experiments upon the direct tensile or cohesive strength of both wrought and cast iron; and, although the experiments were numerous, the results obtained gave much more strength to iron than later experimenters have been able to obtain. But neither Musschenbroek, nor, as far as I have found, any other experimenter, attempted to determine the power of cast-iron to resist a compressing force, like that to which columns are subjected, until near the commencement of the present century. As early as the year 1757, however, Euler published a paper in the Berlin Memoirs, which seems to be a sequel to some previous work of his upon the subject that I have not seen. This paper consists of an elaborate geometrical investigation of the comparative strength of columns of the same materials, but of different diameters and lengths, without, however, determining the *absolute* strength of any one material, or any one size of column, as this indeed could be done only by experiment. No proper and useful practical rules, applicable to cast-iron or stone, could therefore be drawn from the conclusions arrived at. But the theoretical conclusions of Euler deserve to be noticed, both on account of the great mathematical power of the man, and the somewhat near conformity which his formula bears to the truth, as derived from the latest and best experiments. Euler's results may be summed up in a very few words. They were these: — With columns of the same material and of equal diameters, but of different lengths, the strength must be inversely as the squares of the lengths. If the lengths be equal and the diameters unequal, the strength must be as the fourth powers of the diameters directly. Thus, let A and B be two columns of equal diameters, B being twice as tall as A. A will bear four times the load carried by B. And if C and D be two columns of equal height, D being twice the diameter of C, then D will bear sixteen times the load borne by C, or, in general, $P = \frac{d^4}{l^2}$.

Here the application of science to columns, or at least to cast-iron columns, rested, until some time near the commencement of the present century, before which time, indeed, none were used in this country. Younger men than I can well remember when there was not a cast-iron pillar bearing up a single wall or floor in Boston, though they now constitute the principal support of enormous piles scattered through every street. In England the use of cast-iron commenced somewhat earlier than in this country, as the material was there much cheaper, and the art of founding it practised more perfectly. In both countries, however, it was used with much caution. The engineers best acquainted with it knew its uncertain, not to say treacherous character. They proceeded, therefore, with great caution, taking care to make a great allowance for defective workmanship, and the disturbing influences of change of temperature, movements in foundation walls by the yielding or freezing of the earth, vibrations from moving loads, and the motion of machines, and other influences. By this cautious mode of proceeding they kept within the limits of safety, though sometimes, no doubt, with a prodigal use of iron.

It seems that in the year 1795, Mr. Reynolds, a well-known engineer, made two or three experiments upon the powers of bars, one inch square and three feet long, to sustain weights pressing upon them endwise. But these experiments are not related with sufficient detail to have furnished any useful conclusions.

In the year 1818, Mr. George Rennie published in the Philosophical Transactions an account of his experiments on the power of cast-iron to resist a crushing force. These experiments were confined to small specimens in the form of cubes and prisms. The largest cubes, having sides of one fourth of an inch, being crushed by 12,666 pounds, and the largest prisms, of one fourth of an inch base by one inch in height, being crushed by 6,440 pounds. Experiments like these would form a very insecure foundation for any rule to determine the strength of long columns, however, because such columns are not destroyed by being really crushed, but by being crippled by the compressing force, bending sidewise and breaking transversely.

About two years after the publication of Mr. Rennie's paper, Mr. Tredgold, a man who attained, and that deservedly, a high reputation as a writer upon engineering, endeavored to find from the very scanty materials then existing, by geometrical methods, the absolute strength of cast-iron pillars of all sizes; and to give rules to be used by practical builders, that should be trustworthy for their guidance. Mr.

Tredgold devised a formula, from which tables have been calculated that have gone into general use, and are now in the hand-books used by builders. I have here one of these hand-books, published by Weale of London in 1859, and of which these tables form a part. I shall return to them presently.

The next important step in these investigations, taking the order of time, was made by Mr. Hodgkinson, about the year 1836. Mr. Hodgkinson was even then most advantageously known for his experiments upon iron in the form of girders, or when exposed to cross-fracture. His experiments upon columns or pillars were very numerous, amounting to near three hundred, and were admirably contrived; and on reading his clear account of them, one only regrets that they were not extended to greater instances, and not confined, as they were, to loads of less than twenty-five tons, although, indeed, this is a greater weight than had ever been used before for experiment. In the account of these experiments, we have the weights required to destroy solid pillars of from 60 inches in length down to 7½ inches, having their diameters from half an inch up to two inches. To state a few of his results in a very general way. He found that pillars 60 inches long, half an inch in diameter, were broken by a weight of 143 pounds; 30 inches long, half an inch in diameter, by 539 pounds; 15 inches long, half an inch in diameter, by 1,904 pounds.

These were the breaking weights when both ends of the pillars were rounded so as to bear only upon the centre of the pillar. Now these numbers are to each other as 1, 3¾, and 13⅓. The squares of the lengths, if taken inversely, would be 1, 4, and 16. These ratios were maintained as well when the ends of the pillars were flat, as when they were rounded; but when flat, so as to bear upon every part of the end, the actual power of the pillar to sustain pressure was increased about threefold. Again, with pillars of the same length, viz. 60 inches, but of different diameters, he found, that those with a diameter of half an inch broke with a weight of 143 pounds; those with a diameter of one inch, with 1,902 pounds; those with a diameter of two inches, with 24,291 pounds.

These numbers are to each other as 1, 13½, and 170, while the cubes of the diameters are to each other as 1, 8, and 64; the fourth powers or squares of the squares are as 1, 16, and 256. The ratio, therefore, is much above that of the cubes of the diameters, and below that which Euler had assigned, namely, the squares of the squares or fourth powers.

Mr. Hodgkinson endeavored, by a careful and minute analysis, to obtain fractional exponents that should express, in a single formula, the relations of strength, for both difference of height and diameter, with more exactness than any hitherto proposed; and he arrived, after examining many other powers, at the formula $\frac{d^{3.6}}{l^{1.7}}$, d being the diameter, l the length, as giving the relation of strength for cast-iron pillars of different sizes; and this may be taken with perfect confidence as giving the *utmost* strength within the limits to which experiment has been carried. The above formula merely determines the *comparative* strength of pillars of different sizes and proportions. To obtain the actual strength of any pillar, Mr. Hodgkinson, finding the diameter d, in inches, and the length, l, in feet, and taking, for pillars with round ends, 14.9 for a coefficient, gives $14.9 \frac{d^{3.6}}{l^{1.7}} = W$, the weight in tons that the pillar will just break under; and changing the coefficient 14.9 to 44.7, he obtains the weight that will break pillars with square or flat ends. These coefficients were obtained by him as a mean, from a careful comparison of all his experiments, and appear to be, as I have before said of his exponents, sufficiently near the truth to be relied upon for all iron of good quality. At the same time, I think we ought always to be aware of the caution given by Biot, and "trust no such formula much beyond the light of experiment." While Hodgkinson thus gives a much more exact formula than that of Euler for cast-iron pillars, he retains that of Euler for wooden columns, as preferable to his own.

Besides this course of experiments upon solid pillars, he made a very good series upon those formed hollow. These ranged through diameters from 1¾ inches up to 3½ inches, the thickness varying from .28 to .33 inch; the same length, namely, 7½ feet, being taken in all cases. The greatest breaking weight used was 50,477 pounds. These experiments seem to have been as well contrived and executed as those upon solid pillars; and while they show with more exactness than had before been given the vast increase of strength obtained from a given quantity of iron by casting it in the hollow, rather than in the solid form, they did not reach up to sizes large enough to determine beyond a doubt, from this law of increase, a rule which may be perfectly relied upon for hollow pillars of very large size, with very thin walls. He found that his formula, as applied to solid pillars, was applicable to those of a hollow form, by merely changing $d^{3.6}$ into $d^{3.6} - e^{3.6}$, in which d and e are the external and internal diameters, respectively.

Mr. Hodgkinson likewise extended his experiments to some other materials than cast-iron, as wood, wrought-iron, and cast-steel.

Taken altogether, these researches are undoubtedly the most valuable that have been made upon the subject. But after all, Mr. Hodgkinson's paper must be considered in the light he intended it for; namely, as a scientific investigation of the strength of pillars, and not a practical treatise, giving to architects and builders rules that they may follow with confidence in their erections. As the matter now stands, each architect or engineer who would follow this paper must, after finding the limit of strength for any proposed column, determine for himself how far he will keep within this limit, or where safety ends and danger begins. To show how far it is required in practice to carry the strength beyond that assigned by inferences founded upon calculation, to obtain security against all disturbances, and the imperfections of workmanship, I will cite an example or two. A water-pipe 12 inches in diameter, and half an inch thick, ought, from deductions made from the tensile strength of cast-iron, to sustain a column of water more than 3,000 feet high. But where is the engineer that would dare to load a series of such pipes with a column of 300 feet high? Again, a steam-boiler 30 inches in diameter and $\frac{1}{4}$ of an inch thick, ought to hold steam of more than 1,000 pounds' elastic force. But in practice 60 pounds is considered enough for such a boiler. These instances should certainly, in the case of cast-iron pillars, teach us to keep widely within the ultimate, or what may be called the theoretical strength. No practical directions have, as far as I know, been given in any engineering work founded upon Hodgkinson's experiments. The tables by which architects in Boston are governed are derived from the formula of Tredgold, to which I have before alluded. I will finish what I have to say, by comparing a few of the numbers of these tables with each other, and with the experiments and formula of Hodgkinson. I take from these tables a solid pillar 2 inches in diameter, 6 feet long. To this the load assigned is 61 cwt., while 2 inches' diameter 12 feet long is made to carry 32 cwt.; numbers very nearly in the inverse ratio of the height. Hodgkinson gives for the ratio of these lengths 1 to $3\frac{1}{4}$, and Euler 1 to 4.

Again, I take from these tables a pillar

8 inches in diameter, 6 feet long, and the breaking weight is 1,315 cwt.
8 inches in diameter, 12 feet long, " " " 1,224 "

Or, it loses only about 9 per cent by being of double height. While the ratios assigned by Hodgkinson would be, as before, 1 to $3\frac{1}{4}$, and by Euler 1 to 4.

Again, how do these diameters compare, taking for the same lengths? We have:

12 feet long, 2 inches in diameter, bearing . . . 32 cwt.
12 feet long, 8 inches in diameter, bearing . . . 1,224 "

Or about as 1 to 40. While the formula of Hodgkinson gives the ratios to these diameters as 1 to 147, and Euler's formula 1 to 256.

Next for a comparison of hollow pillars. Hodgkinson found that a hollow pillar $7\frac{1}{2}$ feet long, 3.36 inches in external diameter, and .36 of an inch thick, being on round or hemispherical ends, broke only under a load of 50,477 pounds, or $22\frac{1}{2}$ tons. Now, we have in the tables no length under ten feet. Taking this height and the diameter at $3\frac{1}{2}$ inches, with a thickness of half an inch, and to this is assigned a breaking weight of 3 tons 15 cwt., or 75 cwt. But according to Hodgkinson's formula, carried but a very little way from his actual example, such a pillar will sustain a weight of 18.9 tons or 379 cwt. with round ends, or 56.7 tons or 1,138 cwt. with flat ends. Again, to find from the tables a hollow column 10 feet long that will bear a weight of 18.9 tons, I find that it should be 8 inches in diameter and $\frac{3}{4}$ inch thick, and to bear 56 tons it should be 11 inches in diameter and $1\frac{1}{2}$ inches thick.

We see, therefore, that whatever discrepancies and incongruities these tables may contain, they are all, most probably, within the limits of safety, though the longest and smallest solid pillars are but just within those limits; while certainly the large and short ones are safe to a somewhat prodigal use of iron. But ought these incongruous rules to be followed? Safety, absolute safety, against all ordinary, and some even extraordinary circumstances, should first be provided for; beyond that, weight of iron is almost waste of iron; and it seems to me that it would be a good service to mark out where this line is, under different conditions, and to give rules for keeping safely within it, — rules that shall be consistent with the law of strength for small as well as for large columns.

Whereupon a committee, consisting of Daniel Treadwell of Cambridge, J. B. Francis of Lowell, and J. B. Henck of Boston, was appointed to examine and report upon the whole subject.

Professor G. P. Bond communicated the results of a series of photographic experiments, executed at his request by Mr. Whipple, upon the light of the Sun and Moon, compared with that of the planet Jupiter.

The results tend to support the suggestion that the latter is a self-luminous body. Several analogies were pointed out. The physical constitution of the atmospheres of the Sun and Jupiter, the periods of the solar spots, and the phenomena attending the transits of the satellites of Jupiter, were referred to in the same connection.

Professor Bond stated that a phosphorescent condition of the atmospheres of the larger planets might be anticipated as a consequence of Vaughan's theory of the source of solar heat and light, and that this consideration had first suggested the experiments in question. His object, however, was not at all to advocate the theory, but rather to present a variety of facts, all tending to show a remarkable analogy between the Sun and the largest planet of the system.

Dr. Holmes proposed the term *Reflex Vision* to characterize the visual acts illustrated by the following experiments: —

1. Close one eye, leaving the other open. Hold a finger between the open eye and some small object, so as to conceal this object. Open the other eye, and the object will be seen as if through the finger.

2. Place the hand edgewise between the eyes, so that the eye last opened cannot see the finger. The object will still be seen as if through the finger.

3. Place a wafer on the back of a paper stereograph, so that it can be seen in the instrument by one eye only; for instance, the left. An image of the wafer will be seen in the right side of the stereoscope, which cannot always be distinguished from the wafer itself, except by trying it with the finger, or in some similar way. The left image may be called *direct*, the right, *secondary*.

4. Trace a circle round the secondary image with a lead pencil. Fasten a wafer on the end of a narrow strip of card. Push this wafer into the circle just traced. The two wafers will coincide, and appear as one. Draw the wafer gradually away, and it will carry the secondary image with it, leaving the circle blank. Continue drawing it away, and at a certain distance (about one diameter of the wafer, for instance) the secondary image will separate from the moving wafer, and sail very slowly back into the traced circle.

5. Close one eye and look at a window with the other. Now shut both eyes, and there will be a spectrum of the window in the eye which was opened, and in that only.

6. Repeat the experiment, keeping both eyes open, but in such a position that only one shall see the window. Close both eyes, and there will be a spectrum of the window in both eyes, most distinct, frequently, in the eye to which the window was not visible.

These experiments appear to show that an image formed on one retina produces a retinal spectrum undistinguishable in many cases from a direct retinal image. That the seat of this secondary spectrum is the retina, is shown by the fact that the eye must be opened in order that it shall be perceived. The retina seems to require the stimulus of light in order to repeat the impression. Again, in the sixth experiment, the spectrum in the eye which has not seen the object is like that in the eye which has seen it; and this is always recognized as a retinal spectrum.

If the conclusion from these experiments is correct, the transfer of impressions from one retina to the other falls into the great category of reflected nervous actions, and is properly called *Reflex Vision.* The recognized *connection of the retina by looped fibres,* the decussation of the optic nerves, the connection of the optic ganglia, afford abundant anatomical confirmation of the probability of the suggestions offered.

To state the general result of the experiments briefly: —

If an object, A, is seen by one eye only, both being open, there will be a direct image, a, and a reflex image. a'. The retinal impressions will be represented by $a + a'$.

If A is seen by both eyes, the retinal expression will be $a\ a' + a\ a'$.

If A by one eye, and B by the other, $a\ b' + b\ a'$.

The direct and reflex impressions exactly coincide in the normal state, except so far as ocular parallax makes a difference between them. This want of *precise* coincidence between the superimposed or coinciding direct and reflex images is associated with the idea of solidity, and is reproduced in stereoscopic pictures.

Four hundred and seventy-seventh meeting.

March 6, 1860. — Special Meeting.

The President in the chair.

Mr. E. S. Ritchie exhibited a series of experiments in Magneto-electricity. He gave a brief account of the several steps which had led to the invention of the Ruhmkorff apparatus, and spoke of the effect of the condenser first introduced by Fizeau, which at once converted the instrument into a powerful source of tensional electricity. After alluding to the increased energy which he had been able, by certain modifications, to impart to the apparatus, he proceeded to show its effects by a variety of experiments, exhibiting the spark as transmitted through the air, the charging of the Leyden jar, the illumination of the Torricellian vacuum and of various gases and vapors when greatly rarefied, and the influence of the poles of a powerful magnet on these luminous discharges.

In the course of these experiments he showed the effect of a current of air upon the form of the spark as first observed by Du Moncel; the brilliant explosive spark of the Leyden jar in the outer helix, discovered by Grove; the common and stratified discharges through a tall vacuum-tube containing vapor of turpentine; the same through a tube of uranium glass displaying the characteristic fluorescence; the phenomena of Gassiot's cascade, with the purplish fluorescence of the outer glass and the green of the uranium goblet within; the various-colored light and its stratifications in the rarefied gases of Geissler's Tubes; the strong fluorescence of solution of sulphate of quinine when illuminated by some of these lights; the spectra furnished by others; the attraction and repulsion of a magnetic pole on the luminous strata;